Development of the Upper Air Simulator (UAS) for the Calibration of Radiosondes

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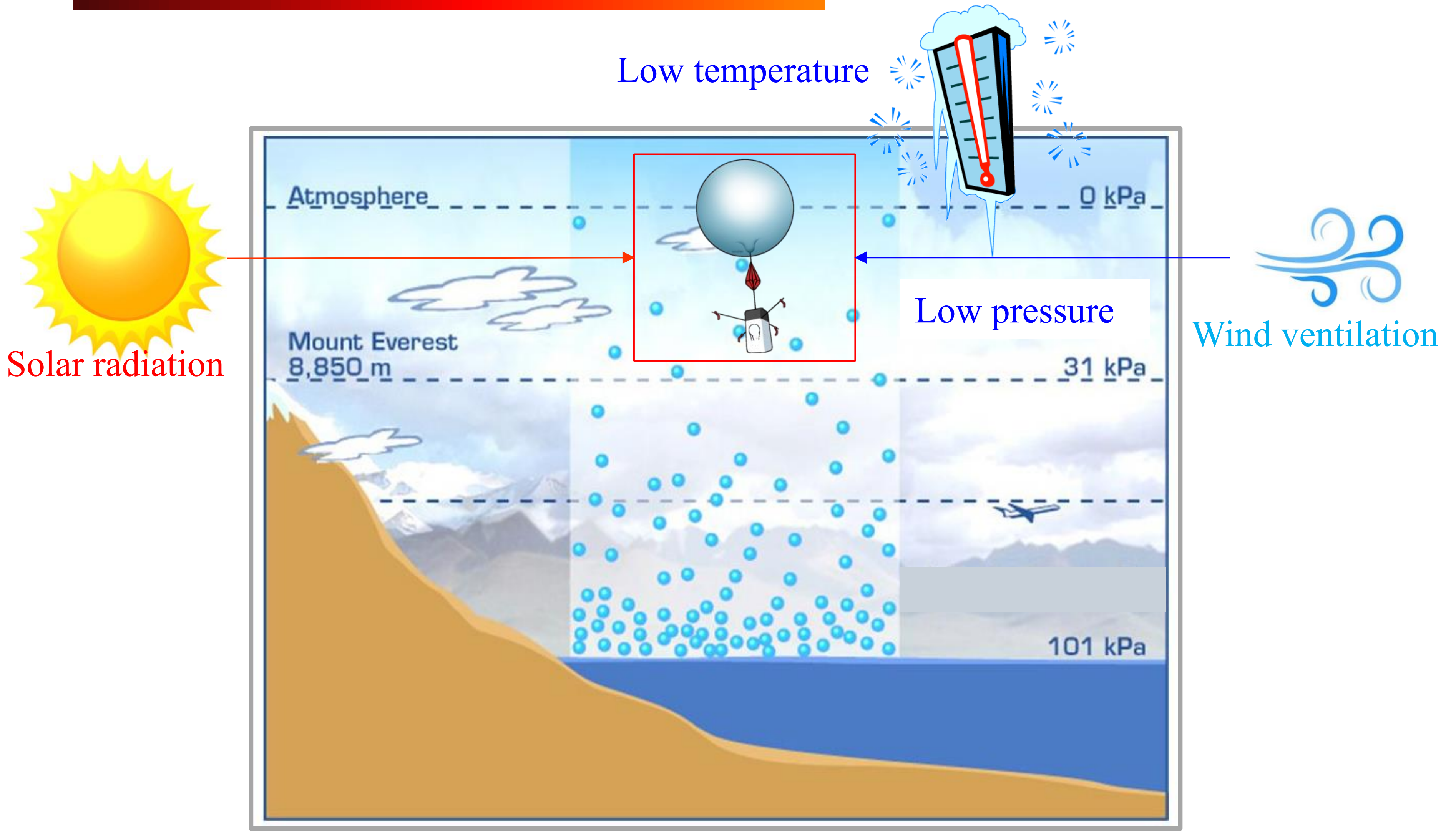
1 Introduction

Radiosonde

- Crucially important instruments for upper-air measurements by WMO
  - Battery-powered telemetry instrument
  - Carried into atmosphere by a weather balloon
  - to measure temperature, humidity, pressure, altitude, geographical position, wind speed and direction, cosmic ray, etc
  - Operated at a radio frequency of 403 MHz ~ 1680 MHz
- **Calibration with high accuracy required.**

Radiosondes in upper air



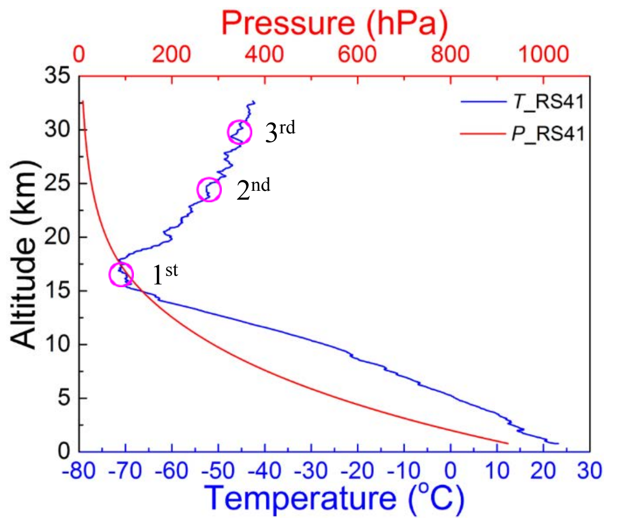
Calibration of radiosonde

- In common, calibration is done at ground laboratory.
  - It cannot reflect the upper air conditions.
  - Radiation effects are the most important parameter.
    - It causes heating in daytime and cooling at nighttime.
    - Low-pressure and low-temperature increases solar heating effects.
    - Air ventilation decreases solar heating effects.
  - There is no combined system which can control all parameters together.
- For the precise calibration of radiosonde, upper air simulation system is required.

In this work

- Upper air simulator (UAS) for radiosonde calibration is designed and constructed.
  - Temperature from -70 °C to ambient
  - Pressure range from 10 hPa to 1000 hPa
  - Solar radiation to 1 500 W/m^2
  - Wind ventilation up to 5 m/s
  - Dew point from -40 °Cdp to 25 °Cdp

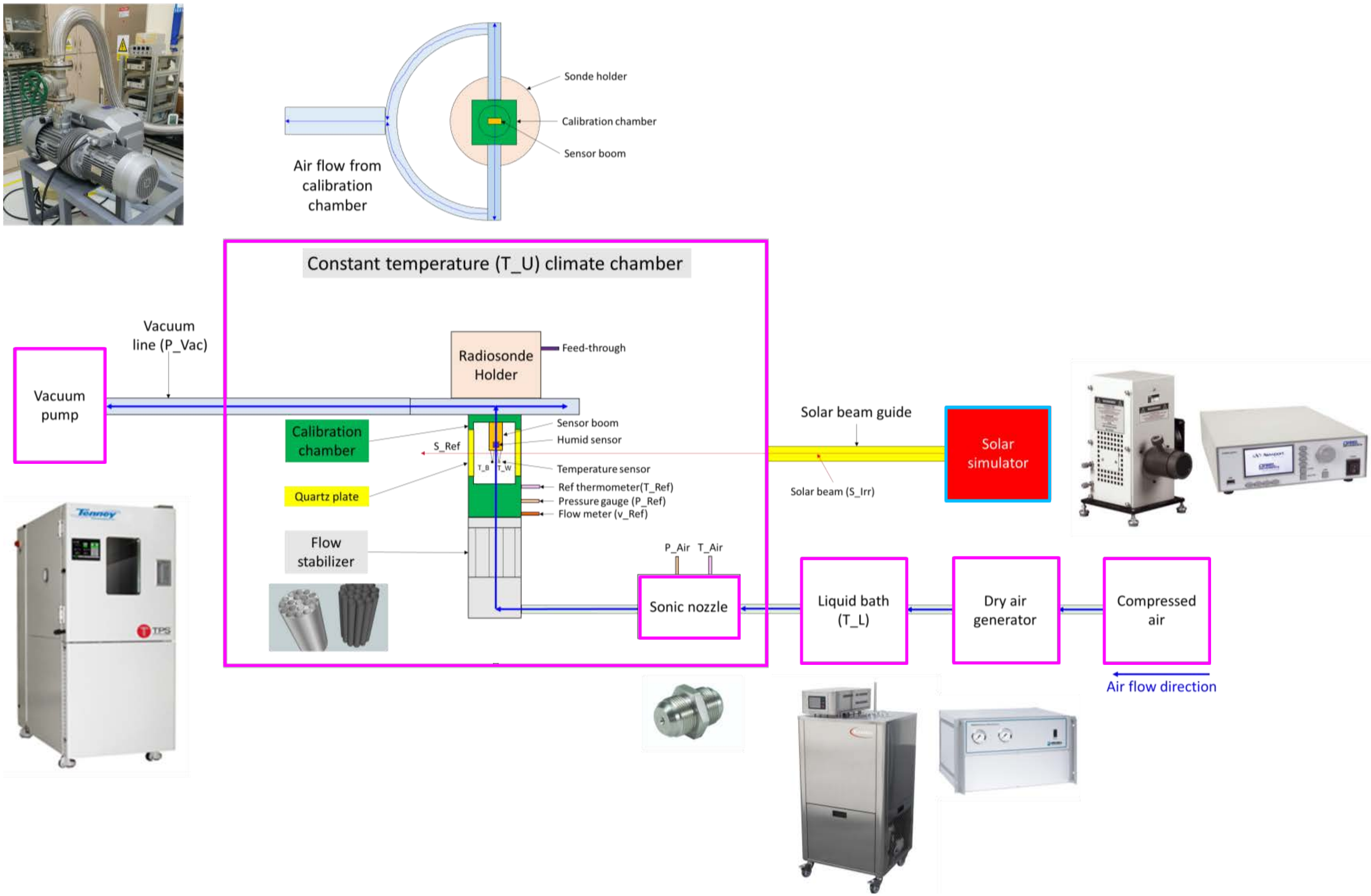
- Temperature sensors of KRISS DTR and Vaisala RS41 tested at 3 points
  - Ventilation about 5 m/s and irradiance about 1000 W/m^2
  - 1st at about 15 km (-70 °C, 100 hPa)
  - 2nd at about 25 km (-50 °C, 50 hPa)
  - 3rd at about 30 km (-40 °C, 10 hPa)



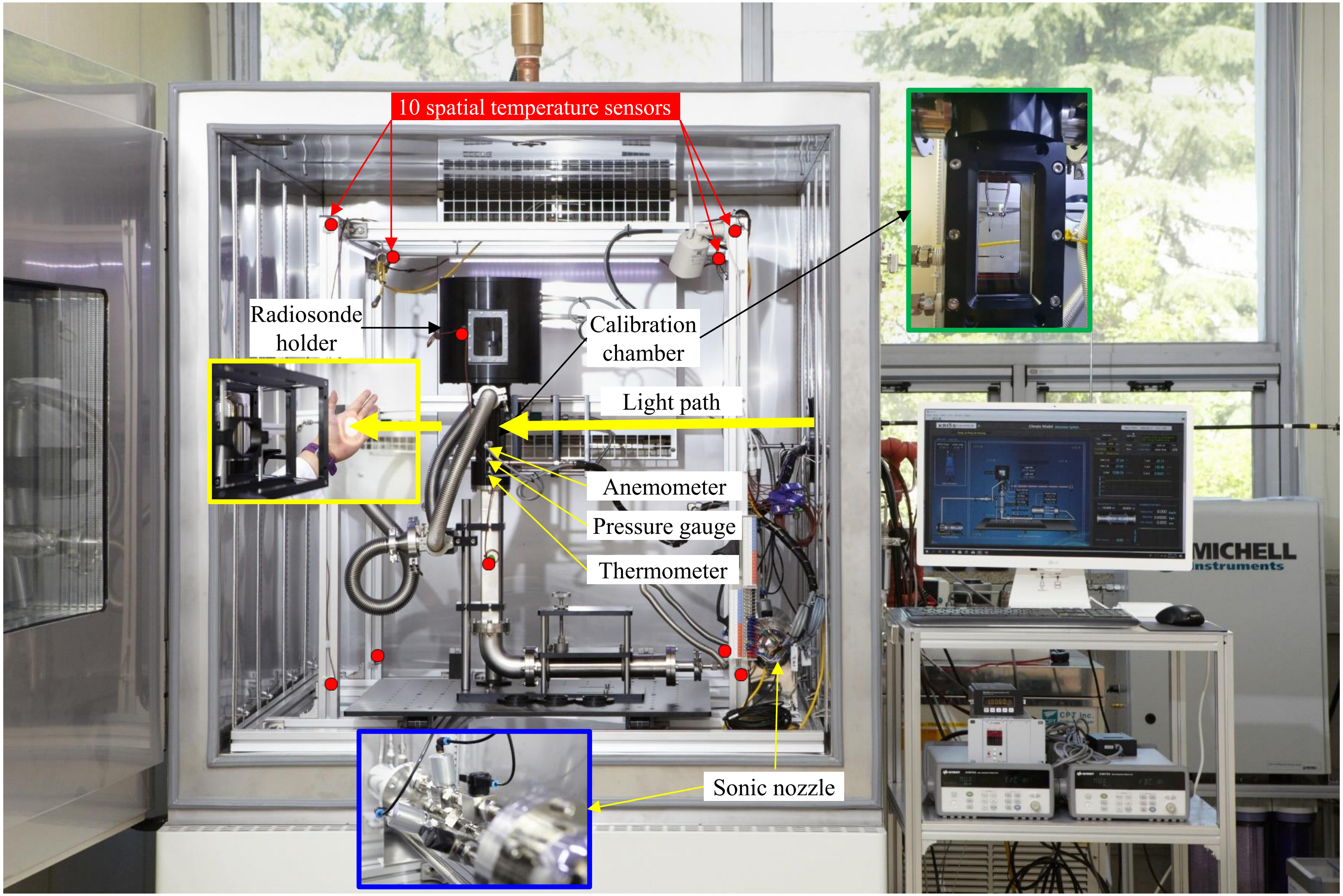
<Temperature profile on Aug. in Korea>

2 Design of UAS

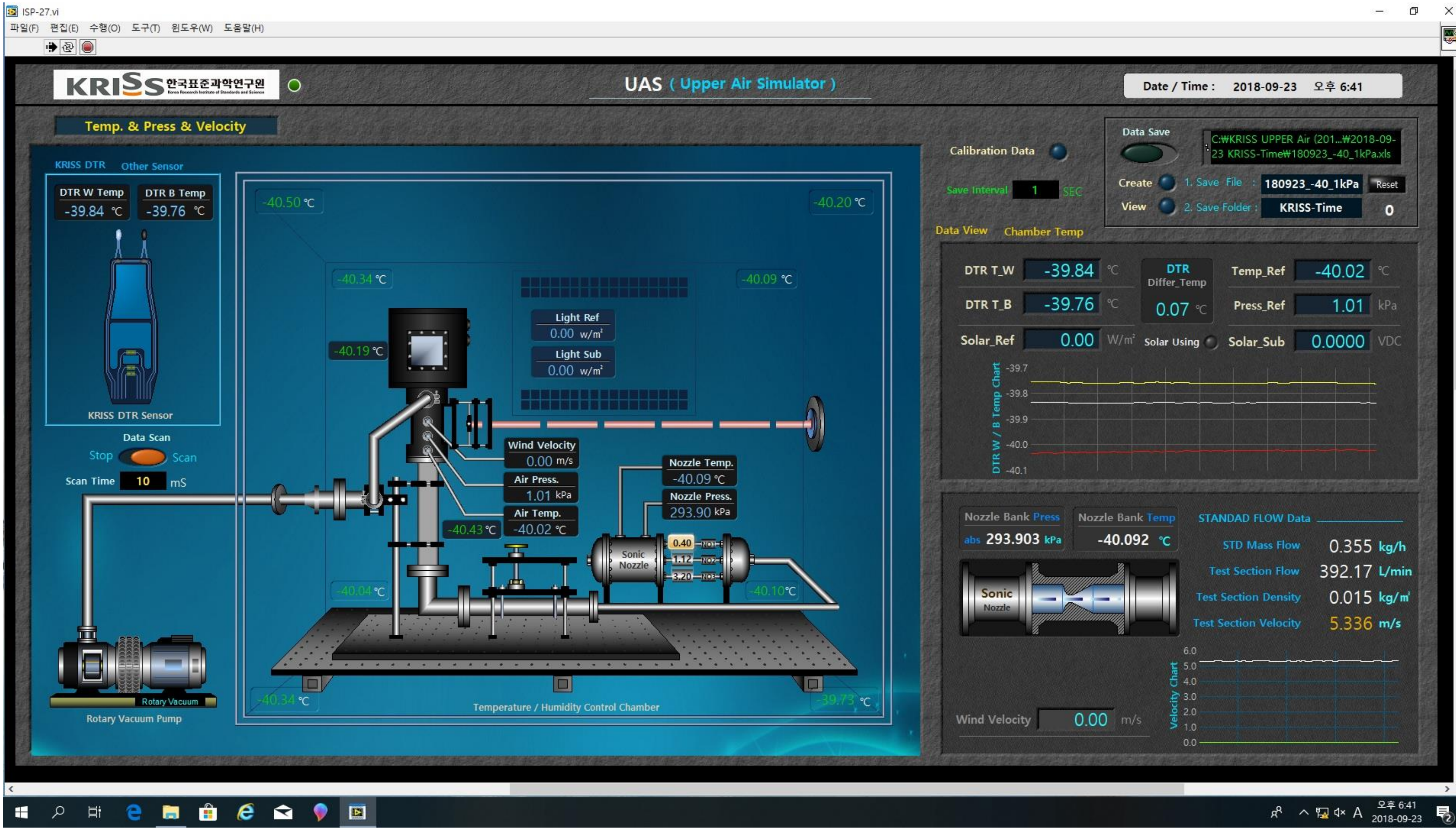
Schematic design of UAS



Constructed UAS



Data acquisition software by Labview



3 Performance of UAS

Air Temperature

Cooling processes

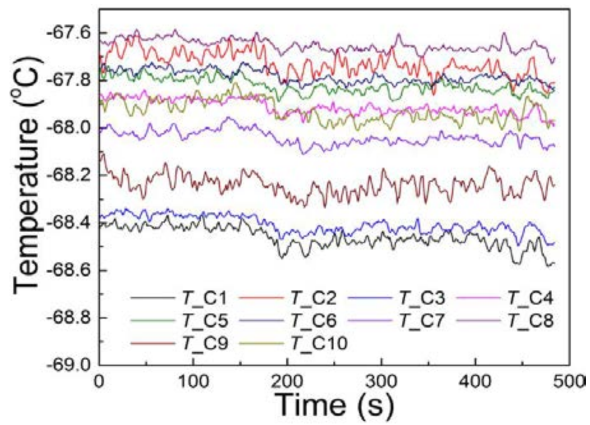
Ambient compressed air

Dry air generator (-100 ^{o}Cdp)

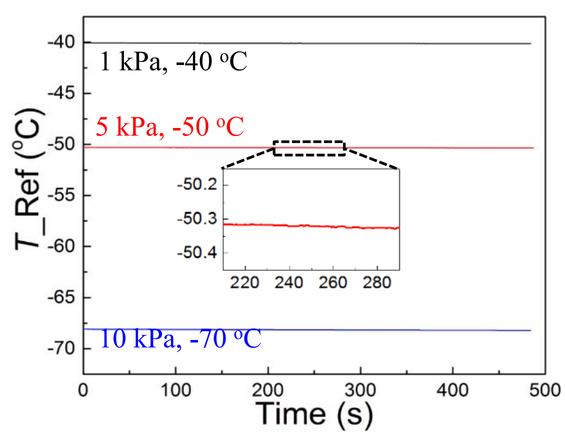
1st cooling at liquid bath

2nd stabilizing in climate chamber

Temperature stability inside chamber@-70 ^{o}C set

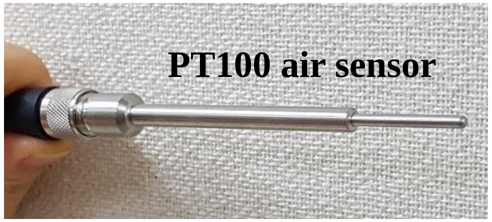


- Type E thermocouple
- Stability of ±0.1 ^{o}C
- Gradient of ±0.4 ^{o}C



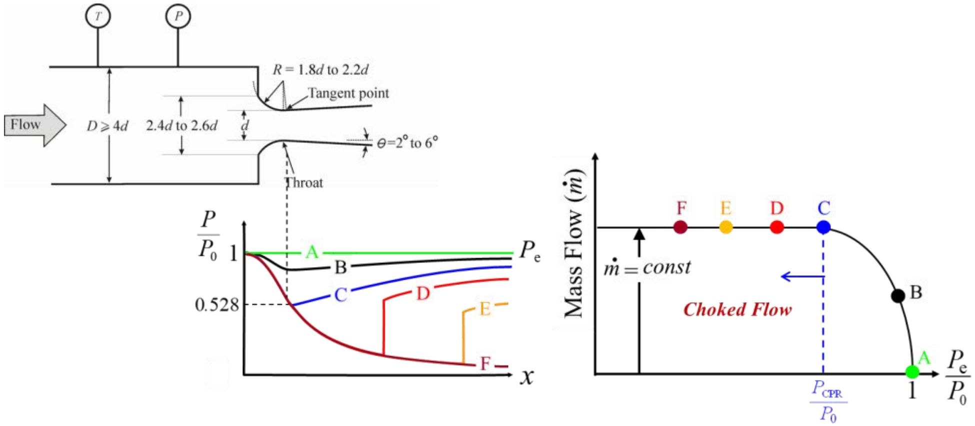
Reference air temperature

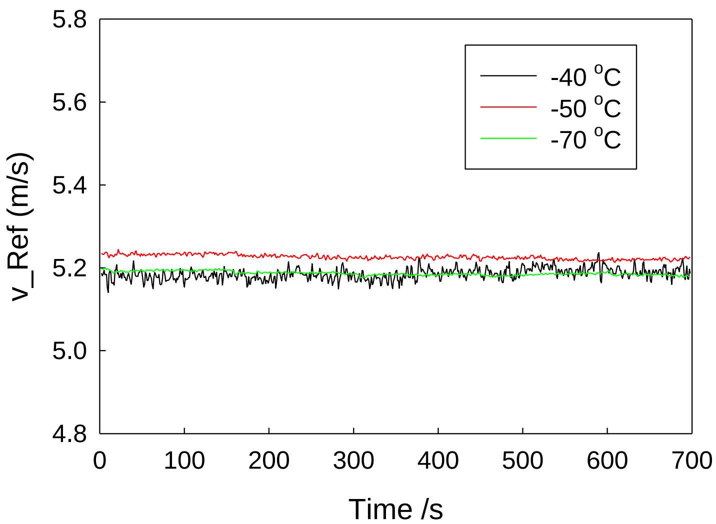
- PT100 thermometer
- Uncertainty of 50 mK(k=2)
- **Stability of ±0.01 ^{o}C**

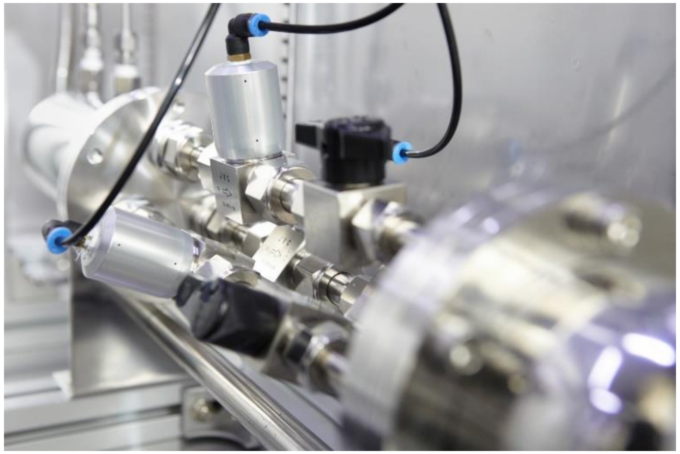


Wind ventilation

- Mass flow control using sonic nozzle
  - Three set of nozzle diameter (*d*)
    - 0.4 mm for about (10 ~ 50)hPa
    - 1.12 mm for about (50 ~ 100)hPa
    - 3.2 mm for about (100 ~ 1 000)hPa
  - Set accuracy of ±0.05 m/s
  - **Stability of ±0.02 m/s**

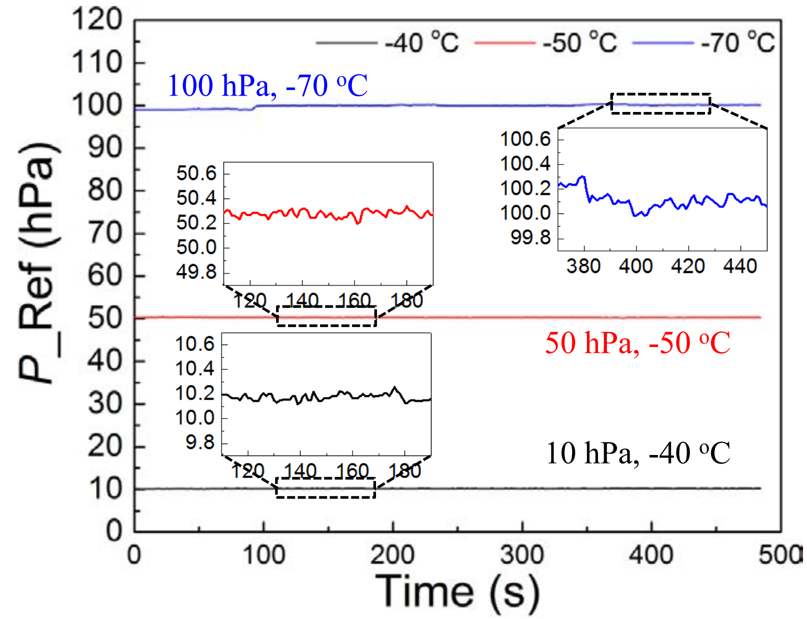




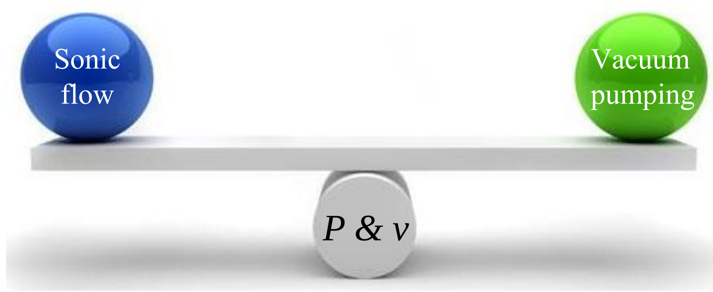


Pressure

- Vacuum gauge
  - INFICON CDG 020D
  - (10 ~ 1000) torr
  - 1 % of reading accuracy

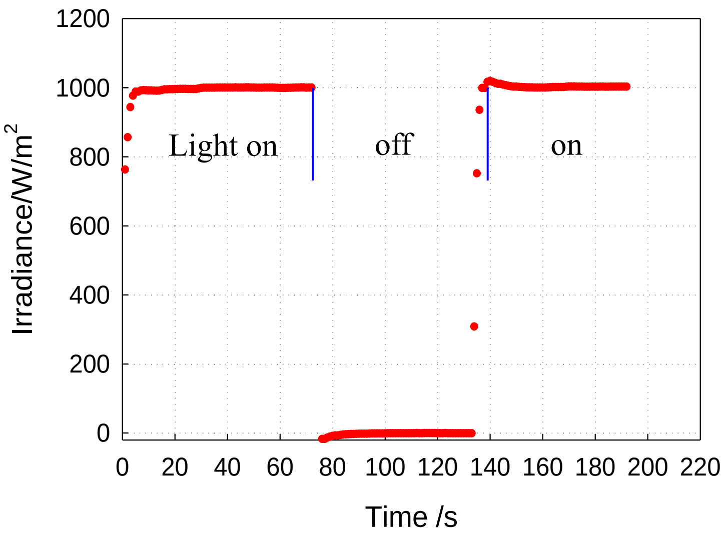


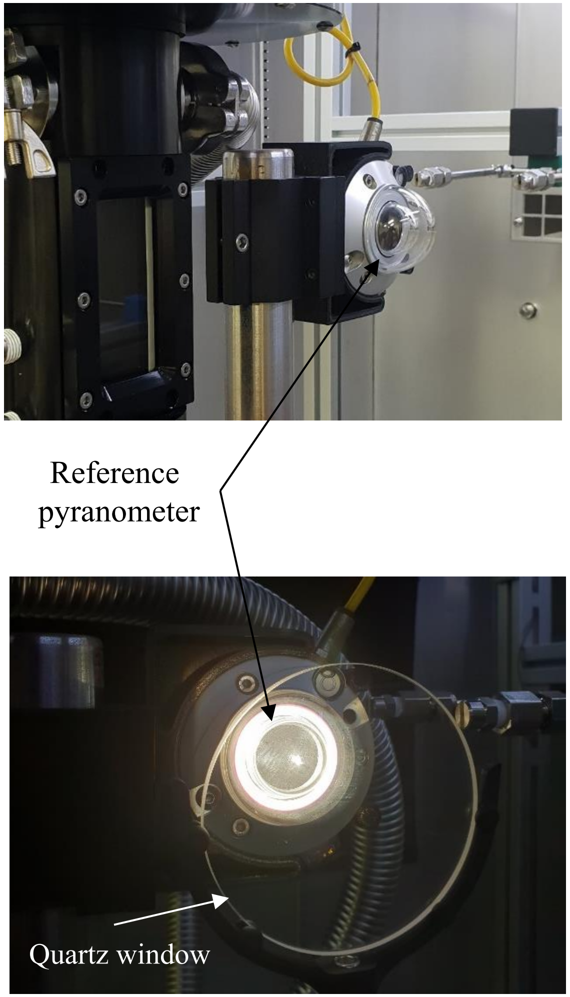
Stability of ± 0.1 hPa



Solar Irradiance

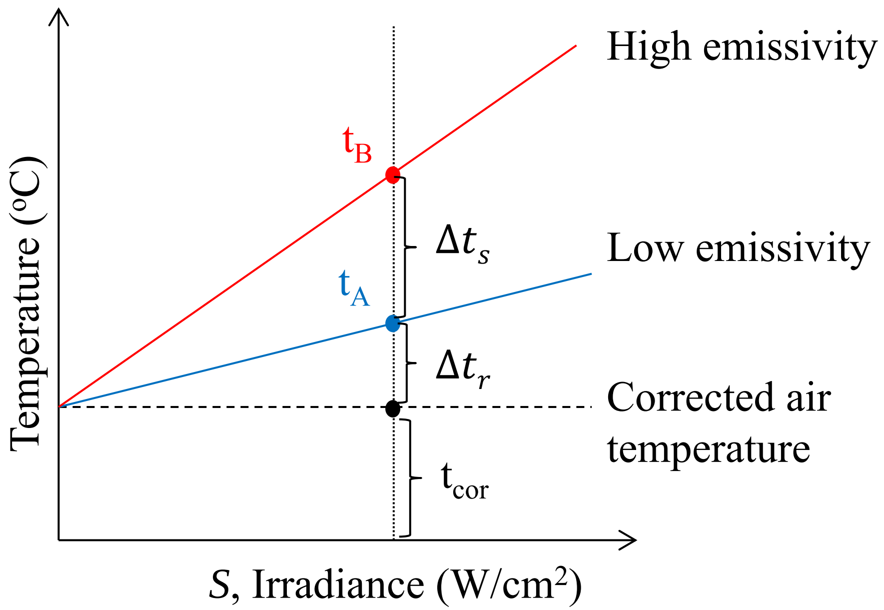
- Solar simulator
  - Newport Research Xe Arc Lamp
  - Max. 1000 W with ozone-free Xe
  - Tested at irradiance (~1000 W/m^2)
  - **Stability of ± 1.5 W/m^2**





4 Calibration of DTR and RS41

DTR (Dual Thermistor Radiosonde)



- $t_B = \Delta t_s + \Delta t_r + t_{cor}$
- $t_{cor} = \boldsymbol{t_B} - \boldsymbol{\Delta t_r} - \boldsymbol{\Delta t_s}$
  - t_B, Δt_s : Can be measured during flight
  - Δt_r: obtained by calibration

$$\Delta t_s = S \times f(T,P,v) \rightarrow S$$

$$\downarrow$$

$$\Delta t_{cor} = S \times g(T,P,v) \rightarrow T_{cor}$$

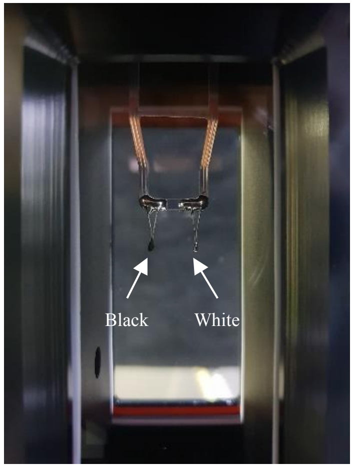
Related Articles

Meteorol. Appl. **23**: 691–697 (2016)
Meteorol. Appl. **25**: 49–55 (2018)
Meteorol. Appl. **25**: 209–216 (2018)
Meteorol. Appl. **25**: 283–291 (2018)
Patent FI 127041 B
Patent KR 1742906
Patent KR 1787189
Patent US 15/306,697

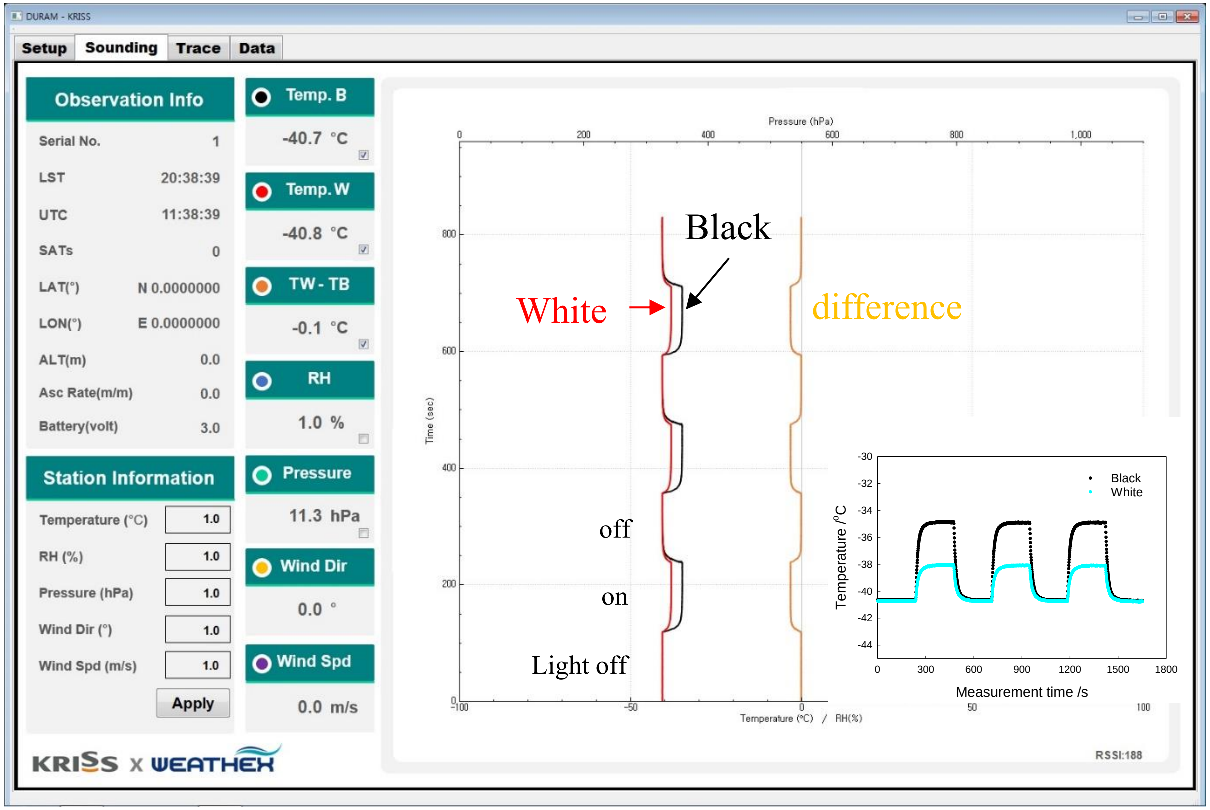
Real time *in-situ* radiation correction technique

Setup of DTR

- DTR (Dual Thermistor Radiosonde) and DURAM sounding system
  - *In-situ* on sounding solar correction by measuring temperature differences between two thermistors having different emissivity (Black and White)



-40 ^{o}C set, 10 hPa, 5 m/s, 1 000 W/m^2



Calibration results of DTR

Solar irradiance (S) = 1 000 W/m^2

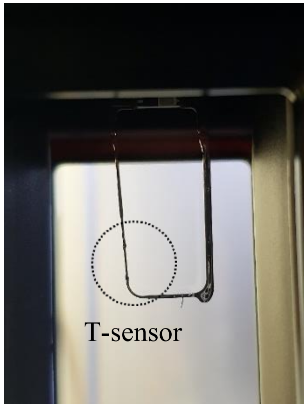
Height /km	Temperature T_{ref}/°C	Pressure *P*/hPa	Air speed *v*/m/s	T_{W_Before} /°C	T_{W_After} /°C	T_{B_Before} /°C	T_{B_After} /°C	$\Delta T_{W,Before}$ /°C	$\Delta T_{W,Rad}$ /°C	ΔT_S /°C
15	-69.0	101.7	5.19	-70.6 ± 0.1	-69.1 ± 0.1	-70.3 ± 0.2	-66.7 ± 0.2	1.6	1.5	2.4
25	-50.5	50.5	5.22	-51.9 ± 0.1	-49.1 ± 0.1	-51.9 ± 0.1	-45.7 ± 0.1	1.4	2.8	3.4
30	-40.3	10.2	5.18	-40.7 ± 0.1	-38.1 ± 0.1	-40.7 ± 0.1	-34.9 ± 0.1	0.4	2.6	3.2

(ΔT (correction value) = reference temperature – measured temperature)

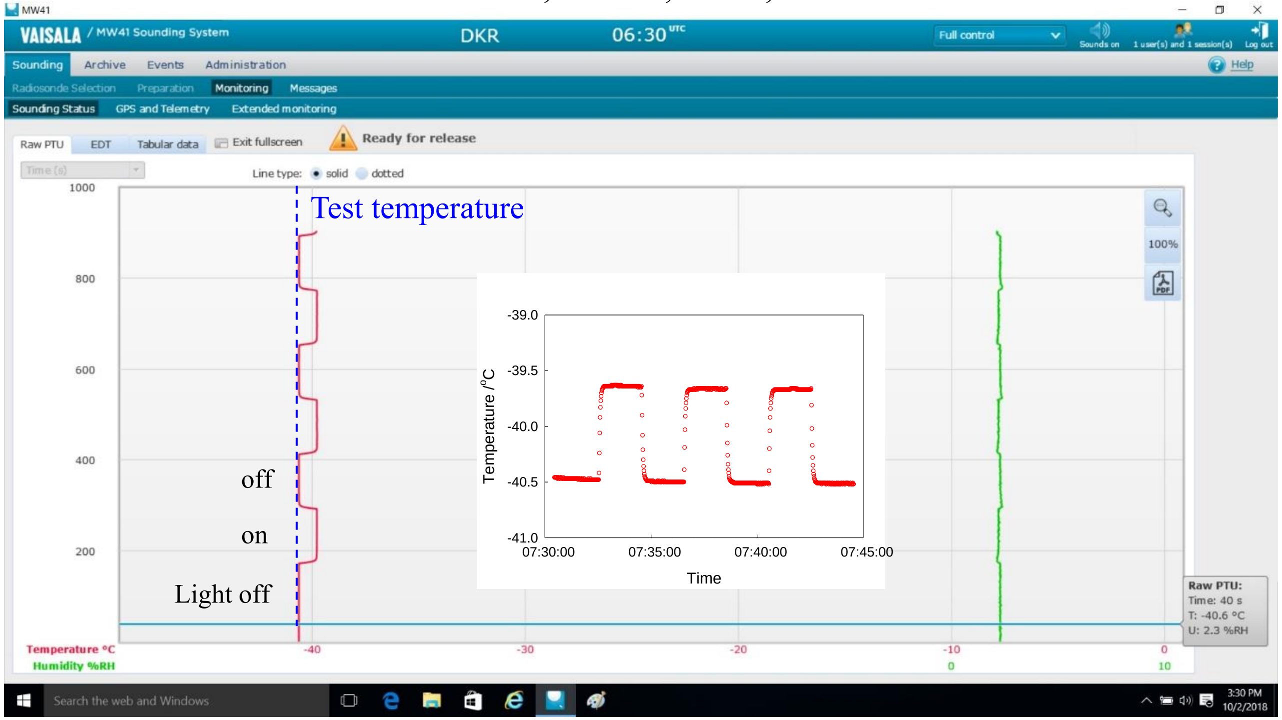
- DTR shows a large temperature rise by solar heating.
- Temperature differences between two thermistors are about 2 ~ 3 °C depending on air condition.
- From the relationship ΔT_s and other parameters (***T, P, v, S***), we can get the in-situ solar correction formula.

Setup of RS41

- Vaisala RS41 and MW41 sounding system
  - Well-known radiosonde with PT1000 Ω resistive temperature sensor



-40 °C set, 10 hPa, 5 m/s, 1 000 W/m²



Calibration results of RS41

Solar irradiance(S) = 1 000 W/m^2

Height /km	**Temperature T_{ref}/°C**	**Pressure P/hPa**	**Air speed v/m/s**	T_{RS41_Before} /°C	T_{RS41_After} /°C	ΔT_{Before} /°C	ΔT_{rad} /°C	ΔT_{cal} /°C
15	-68.5	99.2	5.18	-68.5 ± 0.1	-68.1 ± 0.1	0.0	0.4	0.4
25	-50.4	50.8	5.16	-50.4 ± 0.1	-49.5 ± 0.1	0.0	0.9	0.9
30	-40.5	10.2	5.19	-40.5 ± 0.1	-39.7 ± 0.1	0.0	0.8	0.8

(ΔT (correction value) = reference temperature – measured temperature)

- Temperature accuracy of RS41 is as good as same to the reference temperature.
- It is less affected by solar heating than thermistors.
- At higher altitude, solar correction value increases by about 2 times.

5 Summary

Success in UAS development

- We have developed the **upper air simulator** for the calibration of radiosondes.
  - Air temperature, humidity, pressure, wind ventilation and solar irradiance can be precisely controlled simultaneously.
  - **Sonic nozzle technique** to mimic upper air ventilation is the our best uniqueness.
- **Calibrations of DTR and Vaisala RS41** have been performed in remote mode.
  - Simulation of upper air at -70 °C (15 km, 100 hPa), -50 °C (25 km, 50 hPa) and -40 °C (30 km, 10 hPa) with ventilation speed of 5 m/s and solar irradiance of 1000 W/m^2
  - Solar correction values with altitude are obtained with high measurement accuracy.
- Any radiosondes in market can be calibrated at various air conditions.
- Collaborations with other institutes or suppliers are always welcome.

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Further works

- Improvement of control accuracy of UAS including wind velocity profile measurements, rotation of sensor and control of incident beam area
- Calculation of calibration uncertainty and development of calibration procedures
- Improvement of measurement accuracy of DTR
- Development of accurate *in-situ* real time solar correction formula using DTR
- Sounding tests of DTR with formula

Thank you for your attention

And

Thank my team!